DOCUMENT RESUME

ED 190 352 SE 030 983

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TITLE Energy Gain. Teacher's Guide and Student Guide. Net Energy Unit. Draft.
INSTITUTION Michigan State Univ., East Lansing. Cooperative Extension Service.; Michigan State Univ., East Lansing. Science and Mathematics Teaching Center.
SPONS AGENCY Department of Energy, Washington, D.C.; Michigan Dept. of Commerce, Lansing.
PUB DATE 28 Mar 79
GRANT EC-77-6-01-5092
NOTE 23p.; For related documents, see SE 030 975-985 and ED 180 774.

EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS *Class Activities; *Curriculum Development; Decision Making; *Energy; *Energy Conservation; Environmental Education; *Futures (of Society); *Interdisciplinary Approach; Natural Resources; Public Policy; Science Education; Secondary Education; Social Sciences; Solar Radiation
IDENTIFIERS *Energy Education

ABSTRACT

This module focuses on gains and losses of energy as society processes resources for energy production. It particularly focuses on the end point of energy conversion and addresses decisions which society must make concerning benefits and costs of various energy production methods and generating facilities. One class period is needed to impleme t this module. (RE)

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# ENERGY GAIN - TEACHER'S GUIDE

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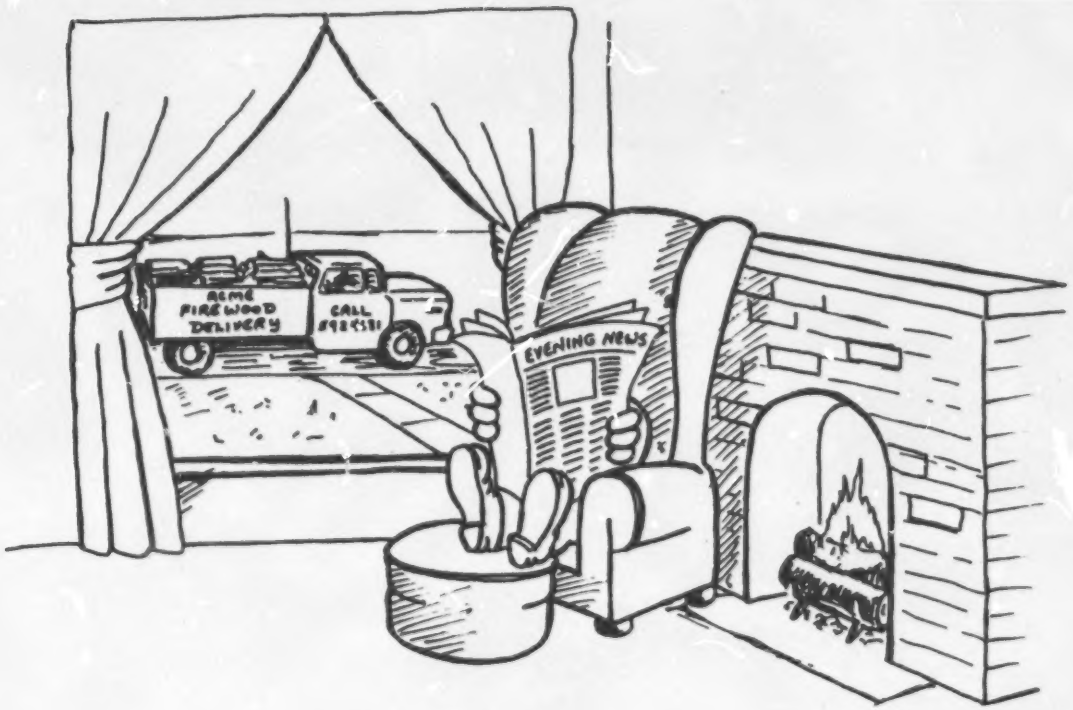


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March 28, 1979

JE 030 983

## ENERGY GAIN

Unit Title: Net Energy

Module Title: Energy Gain

Description of the Module: This module gives additional insight into the concept of energy gain. In particular, it focuses on the end point use of energy as a determinant for the kinds of sources needed.

Unit Objectives Met: 1a, 1b, 1c, 4b, 5a, 5b, 5c

Materials Needed: Student pages and, optional, copies of Net Energy charts in the Unit Teacher's Guide, Appendix B

Module Type: Required

Context: Social Science or Science

Time Required: 1 class period

Mode: Reading, Lecture - discussion

Sample Evaluation Items

The Youth Energy Project is funded by the Michigan Department of Commerce and the Michigan Energy Extension Service on a pilot basis. Michigan State University's Cooperative Extension Service (4-H - Youth Programs) and Science and Mathematics Teaching Center are the project contractors. This material was prepared with the support of the U.S. Department of Energy (DOE) Grant No. EC-77-6-01-5092.

SAMPLE EVALUATION ITEMS

ENERGY GAIN

1. List five kinds of energy that society would have to furnish in order to set up a wind powered generating system in your backyard.

Answer: *Examples of correct responses might include the energy necessary to: 1) form the steel for the tower and parts. 2) Mine the steel. 3) Transport the steel from the mining site to the refinery. 4) Manufacture the various components. 5) Distribute, store and sell the various components. 6) Deliver the components to your home. 7) Erect it.*

2. List five kinds of energy that society would have to furnish in order to provide you with a solar powered swimming pool heater.

Answer: *Similar to answers for number 1.*

3. If the gain of a wind powered system is 10, and society must invest one million BTU's to develop the wind system, how much energy would it deliver if its lifetime is 20 years? 30 years? 40 years?

Answer: *Always 10 million BTU's because the gain only determines how much more energy will be delivered by the system than is furnished by society regardless of its lifetime.*

4. If an energy system will deliver one million BTU's over its lifetime of 20 years, how much will it deliver each year?

Answer: $\frac{1 \text{ million}}{20} = \frac{1 \times 10^6}{2 \times 10} = .5 \times 10^5 = 5 \times 10^4$ BTU/year = 50,000 BTU/year

5. Society should move as quickly as possible in the direction of

a) nuclear light water reactors
b) solar electric generating plants
c) passive domestic heating
d) the development of more fossil fuel plants

Answer: c.

Gain and efficiency are closely related concepts:

$$\text{Gain (G)} = \frac{\text{Energy output } \underline{\text{to}} \text{ society}}{\text{Energy furnished } \underline{\text{by}} \text{ society}} \quad \text{or} \quad G = \frac{E_o}{E_f}$$

$$\text{Efficiency} = \frac{\text{energy output } \underline{\text{to}} \text{ society}}{\text{energy furnished } \underline{\text{by}} \text{ society + energy of the fuel itself}}$$

$$e = \frac{E_o}{E_f + E_i}$$

In both cases, $E_o$ is that output that society wanted. For example, in the Hot Dog Cooking System in the Energy and Efficiency module, society wanted a cooked hot dog. All other energy (heating a room, etc.) was considered "lost." This distinction is important because energy is neither created nor destroyed. From this point of view, the energy output is always equal to the energy input and efficiencies will always be one. However, from a more realistic point of view, the energy output to do the job that society wants is always less than the energy input. Thus, efficiency is always less than one.

Energy gain, since it does not consider the energy of the fuel itself, must be greater than one or have a very good reason for its existence. The fireplace scene, for example, has a gain of less than one, but may be justified on the basis of aesthetics. Solar collectors on satellites have a gain of less than one, but may be the only reasonable source of power for that satellite. If the function of that satellite is considered important to society, the gain of less than one may be justified.

This module will be most interesting if used in a group discussion format. In particular, Activity 1 will be quite revealing as the discussion unfolds. The purpose of this activity is to help students visualize the large variety and amounts of energy that are required to obtain energy.

ENERGY GAIN

INTRODUCTION

In the introductory filmstrip, it was pointed out that it takes energy to get energy. There is no such thing as a 100% efficient system for converting energy from one form to another or for obtaining energy. As fuels or sources of energy become more and more difficult to find, the energy necessary to locate and retrieve these fuels comes closer and closer to the energy delivered by them.

Consider the caveman scene in figure 1. All he had to do to maintain a fire (energy) was to go out and gather wood that had already fallen, bring it in by hand and add it to the fire. The only energy input furnished by him was the food energy necessary to sustain him -- and he probably didn't think of that. In modern times, we, too, use wood, but usually in a fireplace. Now, the energy necessary to keep the fire burning is quite different.

*Point out that the caveman did not cut or split wood, but used wood already fallen and broken. Further, there was no outside energy source needed to transport the wood.

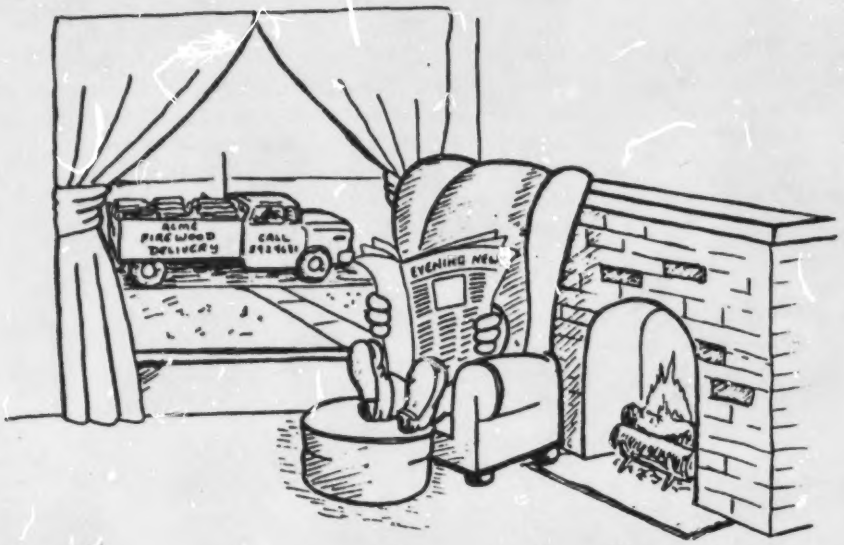



FIGURE 2

Activity 1

Construct a list of the kinds of energy needed to make a scene like Figure 2 possible. Do you think we get more energy out of this system than we put in?

Note: In both examples we excluded the actual energy content of the wood itself. This exclusion is appropriate as long as there is an "infinite supply." However, if the energy supply is limited, we must include the energy of the fuel itself.

*Some examples: 1) Woodcutter drives out to the woodlot. 2) Energy necessary to build and maintain the truck pro-rated over the number of cords of wood delivered. Incidentally, this is not a small number! According to Earl Cook, it takes about 22,000 kilo calories for each dollar of automobile - just to mine the steel, manufacture the automobile and sell it.[1] This is based on the 1968 dollar. If we use a very conservative $3,000 automobile, and convert this figure to BTU's it turns out that the energy cost of producing an automobile is 260 million BTU's. If we assume that a pickup truck requires about the same energy as an automobile and that it would have a lifetime of ten years (very optimistic), we can compute how much of this energy

*can be attributed to a cord of wood. To do this, we might assume a very ambitious woodcutter who cuts and splits one cord of wood each day of the year for ten years. This leaves no vacation time, no holidays, nor any Saturdays and Sundays off. In doing this it turns out that the energy investment of the truck itself amounts to 71,000 BTU's for each cord of wood. The cost of repairing, maintaining, and road construction, etc. turns out to be approximately twice that figure such that the total cost excluding gasoline will be conservatively estimated at 200,000 BTU's per cord of wood.*

*Other information that might be of interest to you and your students is that a cord of wood will deliver approximately 20 million BTU's and each gallon of gasoline delivers 125,000 BTU's. Thus, if the truck uses many gallons of gasoline to go out and cut the wood and deliver it, you might find the modern fireplace has very low gain indeed.*

*For example, the average fireplace is approximately 10% efficient. Thus, each cord of wood would deliver only 2 million BTU's to the house. If the fireplace will deliver only 2 million BTU's per cord and the energy cost of the truck itself is .2 million BTU's, then the gain is*

$$\frac{2 \times 10^6}{2 \times 10^5} = 10.$$

*This is before any of the other energy costs are added in.*

*3) The energy needed to produce the chainsaw. 4) The gasoline necessary to run the chainsaw. 5) The energy necessary to build the mechanical wood splitter used by most commercial suppliers. 6) The gasoline necessary to run the mechanical splitter. 7) The gasoline necessary to deliver the wood and return. 8) The energy needed to build the fireplace. 9) Other?*

For a long time, now, we have operated under the belief that there was more coal, oil and natural gas in the ground than we could ever use. As long as oil and coal were considered unlimited, we could consider electric generating plants based on these fuels as "high gain" systems (i.e., a system that delivers many times more energy to society than society furnishes to operate it). Let's look at coal (Fig. 3).

**Discuss the various kinds of energy that society must furnish in order to deliver electricity to our homes. Figure 3 should suggest many of these. Others that are less visible include the energy needed to build railroads, highway systems, etc. Help the students to expand their understanding of these energy inputs.*

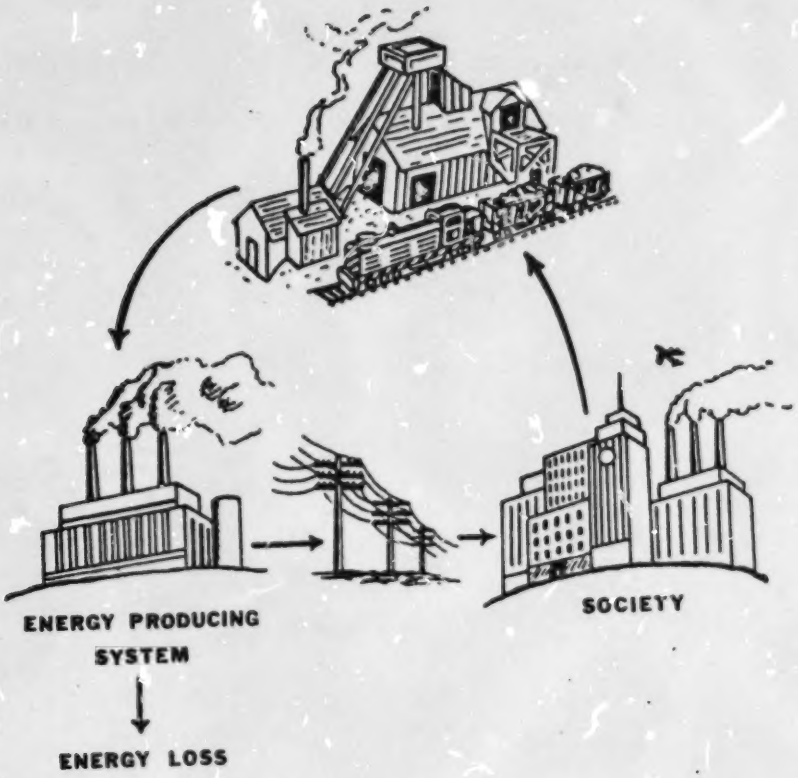



FIGURE 3

In order to convert coal in the ground to electricity in your home, we must furnish energy to mine the coal, build and operate equipment to mine it, process it, and transport the coal to a generating plant. In addition, we must build and operate the generating plant (think of all the energy it took to form the steel, concrete, etc. and construct the plant), and build and maintain transmission lines to your house. This is in addition to the food energy needed by all of the people involved in the process. Whew! Lots of energy.

GAIN AND FOSSIL FUELS

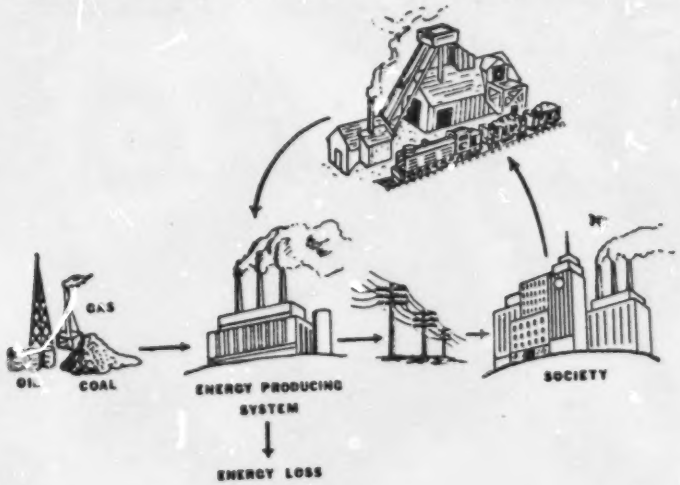
But coal and oil are highly concentrated energy. Only 10 pounds of coal has enough energy to furnish all the hot water an average family of four would need each day. Since fossil fuels are such concentrated energy sources, all the energy needed to build and operate a fossil fuel electric generating system

turns out to be only a small fraction of the energy the system will furnish, approximately 25 times more energy to society during its lifetime than society puts into it. In other words, the gain is 25.

$$\frac{E_o \text{ (output } \underline{\text{to}} \text{ society)}}{E_f \text{ (furnished } \underline{\text{by}} \text{ society)}} = 25$$

What's this about an energy shortage? We have here an energy multiplier of the finest sort -- 25 units of energy output for every unit of energy furnished by society. But alas, our supply of fossil fuels is not endless! Therefore, we must now consider the energy of the coal or oil itself -- the energy furnished by the environment.

FIGURE 4




In fact, because efficiencies are always less than 100% (remember the Efficiency Module) it takes approximately two units of energy from the environment for every unit of energy we get out. The gain now looks much more like:

$$G = \frac{E_o}{E_i + E_f} = \frac{1}{2}$$

This change from 25 to ½ changes the picture a bit. In addition, as fossil fuels become harder to get (deeper, further away and less concentrated) the energy

*Remind the student of the concept of efficiency. Compare Figure 3 and Figure 4. Point out that the concept of gain is only appropriate when the energy furnished by the environment can be considered infinite! Can we really consider fossil fuels infinite?

necessary to obtain them gets much much larger. Thus, the energy furnished by society will become an even larger portion and the gain will go down still further.

GOOD NEWS AND BAD NEWS

The question is, "can we, like the snarfs, find a true energy multiplier?" To that question, there is good news and bad news.

Bad News - No Way! You can never get something for nothing.

Good News - But, if you could find another source of energy that is really infinite, we could again forget $E_i$ ( the energy from the source itself) and concentrate only on the energy furnished by society.

Bad News - There is no infinite supply of energy.

Good News - But, for all practical purposes, the sun, while not infinite, is likely to keep giving us energy at a fairly constant rate for ~~hundreds, thousands, millions, billions~~, lots of years -- longer than we need to worry about. This energy is in the form of direct radiation, conversion to plants and to the rest of the biological food chain, wind, tides, etc. -- and there is lots of it!!

Bad News - It isn't concentrated. It is relatively low density (or dilute). Therefore, we must use a lot of society's energy to collect it.

Good News - But this is the only energy input needed. We don't need to worry about the energy in -- $E_i$.

Well, it seems that the good news outweighs the bad. Let's look at it. First, consider flat-plate collectors for domestic hot-water heating or supple-

mental home heating. Here, the energy needed to build, sell, service, install and distribute the systems tend to be relatively small compared to the energy output over the lifetime of the system -- CONSIDERING THAT SOLAR ENERGY IS FREE AND INFINITE. In fact, these systems will provide real gains of perhaps 10 or more. Passive systems, for example locating glass appropriately, yield even higher gains -- particularly in new homes designed for the system. On the other hand, systems designed to provide high temperature steam for the generation of electricity have considerably lower gains. Here we usually think about collection of energy, concentration (mirrors or lenses), storage (for night and cloudy periods) and conversion to electricity. The system, as described, would probably have a gain of only two to three over its lifetime. Remember the snarf example? With this kind of gain, we can't afford to produce these units at a rapid rate. In general, then, we can say that solar holds excellent promise as supplemental hot water and domestic heating. The energy pay off is relatively high, particularly in the sunny southwest. We cannot, however, look with great hope to solar in the near future as a single or even a major contributor to our industrial and electrical needs.

*The gain for solar systems is a matter of dispute. We have found gain figures ranging from 2 to 200! You or your students may have read similar estimates. The disparity in the estimates arises from many factors including climatic conditions, end point uses (domestic heating versus steam for the generation of electricity), the expected lifetime, and the energy needed to maintain and operate the system over that lifetime. We have chosen to use the more conservative estimates. The important point, however, is that as these gain figures become more precise, whatever their actual number, the student should be able to make reasonable estimates on the desirability of different growth rates for selected gains. It turns out that energy storage for cloudy days and nighttime results in dramatic decreases in gain figures. Thus, systems designed to generate steam which will in turn produce electricity will have very low gains if the system is expected to store energy such that it will have some sustained output over time.

*If you are teaching science, you may want to do an additional activity with your students looking at the growth rate that would be required to achieve various levels of energy output by alternative energy sources. This would be followed by an examination of the payback periods for various gains and selected growth rates. This activity involves quite a bit of mathematics so is included only as an option. Mathematics for determining projected growth rate are included in Appendix A. Appendix B contains a set of net energy charts for selected gain and growth rates. Appendix C is the mathematical derivation of formulas used for deriving the curves in Appendix B.

Nuclear

At present, virtually all of the nuclear plants in the United States are non-breeder, light water reactor plants. Since their efficiency is relatively low compared to fossil fuel plants and their fuel (uranium) finite, they must be placed in the same category as fossil fuel plants. Their gain, considering the energy input, is extremely low. Breeder reactors, however, actually make more fuel than they use. Thus, these generating plants come close to being true energy multipliers. Yet, the problems of waste disposal, societal anxieties about the safety of nuclear power plants, and the production by breeders of large quantities of nuclear "bomb" materials are the bad news items. Nevertheless, the gain appears to be high for breeders. Should we decide to produce them, the technology is ready. The decision is surely more social than technological.

*The best estimates we have for nuclear reactor plants point to a gain of ten to fifteen. This does not, however, include decommissioning the plant nor containment and/or reprocessing of the nuclear waste material. If these factors are included, the gain will plunge still lower.

Fusion

Since this source is not yet scientifically nor technologically feasible, we cannot adequately project gains.

Other

Wind power in appropriate locations appears to have gains that are somewhat higher than direct solar heat converters. Where appropriate, this energy source should be considered as an excellent alternative.

*Wind power, especially for uses such as irrigation pumping, appear to have very reasonable gains -- on the order of 20 to 30. In areas where 15 mph or greater winds are available on a rather consistent basis, the gain may also be 20 to 30 for electrical power generation. Thus, in appropriate locations, windpower seems to be a very desirable alternative.

Summary

With our fossil fuels depleting rapidly, and nuclear breeder reactors the only real hope for high concentration energy, we, as a society, must begin to make some very hard decisions. We are exactly where the snarfs were in their early history when they decided to invest some of their ortep into ortep multipliers. We, too, must invest fossil fuel energy and present nuclear energy into the production of other energy sources. However, we must keep firmly in mind the question of gain. If the system is low gain, we must be extremely careful about how rapidly we expand the use of that system and, at the same time, use its output wisely. In fact, careful planning should allow us to use a combination of energy sources in the future, each matched carefully to its end point use. High temperature solar collectors, for example, have relatively low gain. But they <u>will</u> produce electricity. This electricity can be used in the manufacture and refining of other material resources. At the same time, we don't need those kinds of high temperatures for home heating or domestic hot water heating. We need temperatures no higher than 80-100$^{o}$ for home domestic hot water heating. For these uses, high gain collectors are already available. Thus, it will become a task of carefully identifying what end point uses need high-temperature energy and which can use low-temperature energy and then carefully matching delivery systems to these uses.

*Help your students to understand that in order to build the various kinds of alternative energy sources, we must have available high temperature energy for the formation of steel, glass, etc. Thus, it will require a considerable investment of our fossil fuel energy in order to move into alternative energy sources, even those that will produce only low temperature heat. At the same time, it may be necessary to invest some of our fossil fuel resources into a carefully planned growth pattern to build low gain, high temperature sources that will be necessary for particular end point uses. Thus, we may be moving into a future where end point use becomes a very important consideration when selecting an energy source. We will not be able to afford the luxury of using high temperature sources such as fossil fuels where low temperature sources would suffice.

Activity 2

Identify the uses of energy in your home and your school. Which ones could you easily eliminate? Could you substitute a lower temperature source such as solar for any of these uses?

*An example of the present use of a high temperature source where a low temperature source would adequately suffice is the hair dryer. In this device we use a very high temperature electrical element with all the associated losses of energy that occur in the generation of electricity when the low temperatures provided by solar heat would be more than sufficient. Ask the students if they could design a solar hair dryer. Another example might be the electric or gas clothes dryer. Of course, we could hang the clothes out. However, could we design a clothes dryer that would utilize the 100 to 150° temperatures supplied by a solar collector?

ENERGY GAIN

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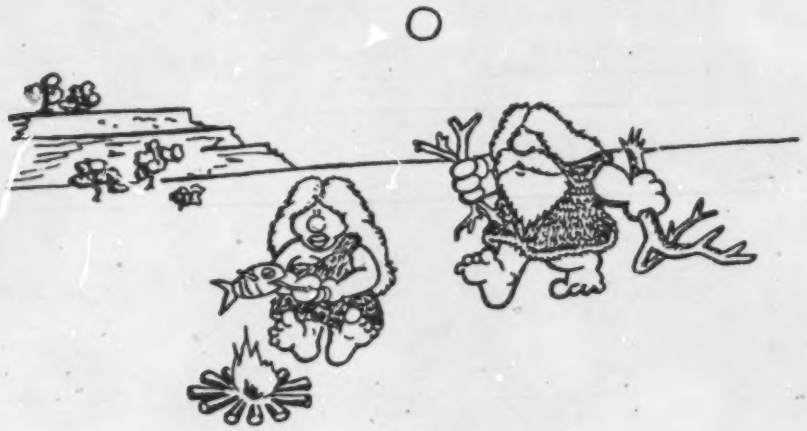

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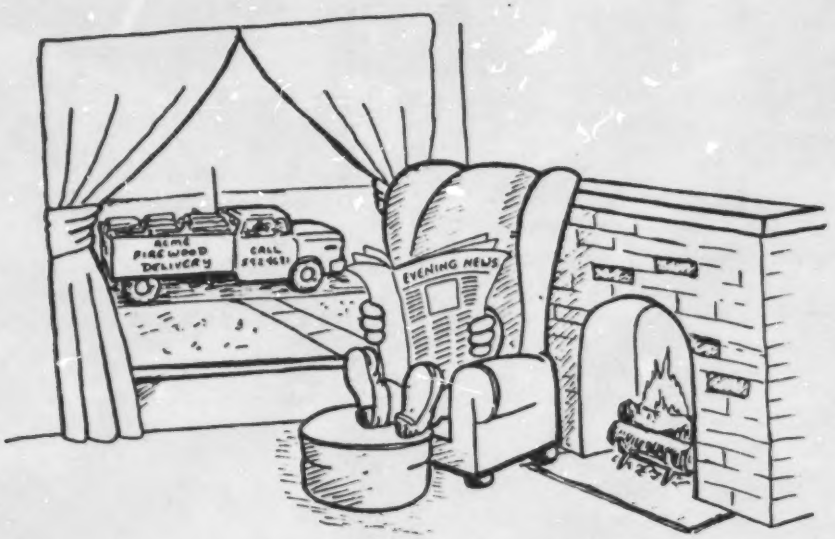


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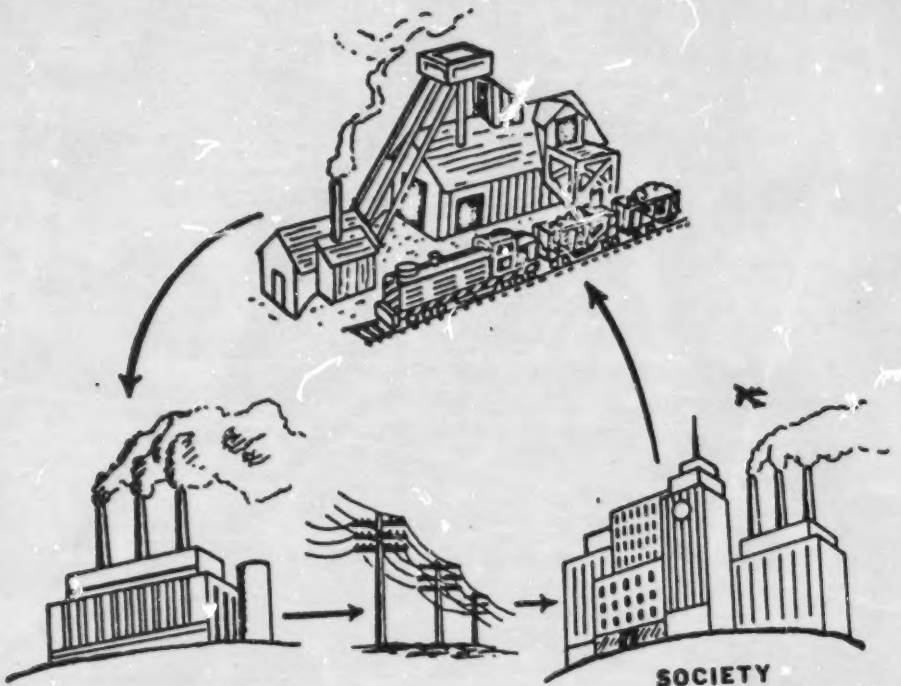


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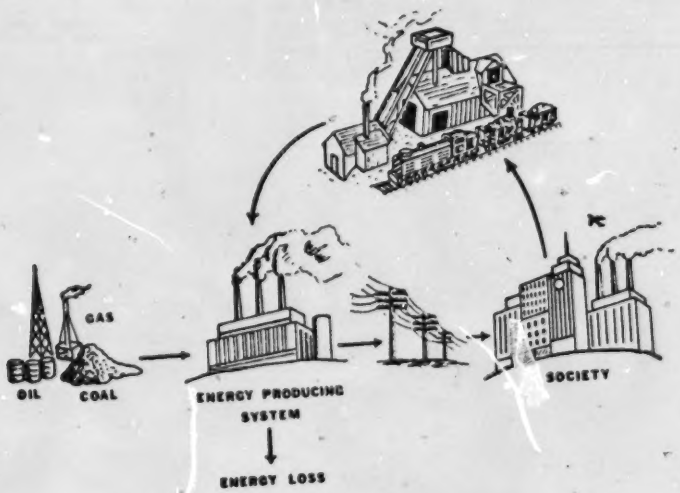


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Summary

With our fossil fuels depleting rapidly, and nuclear breeder reactors the only real hope for high concentration energy, we, as a society, must begin to make some very hard decisions. We are exactly where the snarfs were in their early history when they decided to invest some of their ortep into ortep multipliers. We, too, must invest fossil fuel energy and present nuclear energy into the production of other energy sources. However, we must keep firmly in mind the question of gain. If the system is low gain, we must be extremely careful about how rapidly we expand the use of that system and, at the same time, use its output wisely. In fact, careful planning should allow us to use a combination of energy sources in the future, each matched carefully to its end point use. High temperature solar collectors, for example, have relatively low gain. But they <u>will</u> produce electricity. This electricity can be used in the manufacture and refining of other material resources. At the same time,

we don't need those kinds of high temperatures for home heating or domestic hot water heating. We need temperatures no higher than 80-100° for home domestic hot water heating. For these uses, high gain collectors are already available. Thus, it will become a task of carefully identifying what end point uses need high-temperature energy and which can use low-temperature energy and then carefully matching delivery systems to these uses.

Activity 2

Identify the uses of energy in your home and your school. Which ones could you easily eliminate? Could you substitute a lower temperature source such as solar for any of these uses?